MONTHLY WEATHER REVIEW

Editor, W. J. HUMPHREYS

VOL. 63, No. 7
W.B. No. 1161

JULY 1935

CLOSED SEPTEMBER 3, 1935
ISSUED OCTOBER 14, 1935

ANALYSIS OF A WARM-FRONT-TYPE OCCLUSION

By H. WEXLER

[Weather Bureau, Washington, July 1935]

The weather situation over the Midwest on October 26, 1933, was first brought to the writer's attention by an interesting article by Christensen.[1]

An inspection of the surface and upper-air data proved the situation to be so interesting and the contrasts in the air masses so striking that a closer study was made.

The material here presented includes the analyzed surface-maps and vertical cross-sections for the mornings of October 25, 26, and 27, 1933. The data on the surface maps are arranged in the following manner: The state of weather is entered in the usual way, and the wind direction and velocity are represented by an arrow *flying with the wind*, the number of half-barbs corresponding to the velocity in the Beaufort scale. To the right of the station is entered the temperature in degrees Fahrenheit, and underneath this the 24-hour precipitation in hundredths of an inch. Several stations which report dew-point temperatures have these entered to the right of the temperatures. To the left of the station is entered 3-hourly pressure character, and pressure change in hundredths of an inch. Also, when occasion warrants, above the pressure change are indicated special phenomena, such as thunderstorms that occurred within the previous 24 hours. Above the station are entered the cloud amount, kind, and direction of motion; cirrus-type clouds are omitted in order to save space. Cold fronts are represented by heavy, solid lines; warm fronts, heavy dotted lines; occluded fronts by alternate heavy dashes and dots; and upper-air cold fronts by heavy dashed lines. Falling precipitation is indicated by cross-hatching.

The vertical cross sections are placed so that they face the surface maps to which they correspond. Two sections are shown for each of the three mornings; one, a west-east section including Omaha, Nebr., Cleveland, Ohio, and Boston, Mass.; the other, a north-south section, including Pembina, N. Dak., Omaha, Nebr., and Dallas, Tex. While the number of airplane stations for this study is much smaller than is available now, the situation is so clear-cut that it is possible to make a fairly satisfactory analysis for each of the 3 days. An airplane sounding in the sections is marked by a vertical line, above which the time of the sounding in E. S. T. is indicated. Each significant level in the sounding is indicated by a short horizontal line, around which the following data are placed: to the left is the temperature in degrees centigrade, and underneath this the relative humidity in percent; to the right is potential temperature in degrees absolute centigrade, and below this the specific humidity, in grams of water vapor per kilogram of moist air. At each kilometer is indicated the temperature change since the preceding day. At various levels the wind directions and velocities are represented by barbed arrows flying with the wind; the number of half-barbs corresponds to the velocity in the Beaufort scale. On the west-east sections a horizontal arrow with barbs to the left represents a west wind, while a vertical arrow with barbs at the top stands for a northerly wind. However, on the north-south sections, a horizontal arrow with barbs to the left represents a north wind, while a west wind is shown by a vertical arrow with barbs at the bottom. Clouds, haze, ice, etc., are entered at their respective elevations; if the elevations are unknown, then these phenomena are entered above the top of the sounding. Cold fronts are shown as heavy solid lines, warm fronts as heavy dotted, and subsidence inversions as heavy dashed lines. Isotherms are drawn for each 5°, and isopleths of specific humidity (grams of water vapor per kilogram of moist air, indicated by q) for each gram. All elevations referred to in the text are given in meters above sea level.

On the morning of October 25 most of the continent at the surface was covered by polar air masses. (Fig. 1.) Over the plateau region, an N_{PP} air mass [2] was advancing, displacing before it a narrow sector of N_{TP} air. The N_{PP} air had been considerably modified by a lengthy passage over the southern part of the North Pacific Ocean and was only slightly cooler at the surface than the N_{TP} air. The front separating the two air masses was clearly marked by a discontinuity in the 3-hour pressure characteristics. The surface temperatures in the N_{TP} air were low, partly because of radiational cooling of the ground on the plateau and partly because the valleys still contained remnants of an old N_{PP} air mass. To the east of the N_{TP} sector were two polar continental air masses, covering the remainder of the continent. The first of these was an N_{PC} mass, which had moved very slowly southward from the North Central States on the 22d, reaching the Gulf States and the Gulf of Mexico on the 25th. This air was considerably modified, its heat and moisture contents being much higher than the fresher P_C air mass which was moving swiftly southward behind a deep LOW that was centered off the Maine coast. The warm sector of this

[1] A. H. Christensen, Analysis of a Warm "Cold Front." MONTHLY WEATHER REVIEW, volume 63, January 1935, page 9.

[2] For a description of American air masses see H. C. Willett, "American Air Mass Properties." Papers in physical Oceanography and Meteorology, M. I. T. and Woods Hole Ocean. Inst., Volume II, No. 2.

LOW was a broad current of tropical maritime air which extended northward past Nova Scotia. In the Canadian northwest, on the front separating the Pacific from the continental air masses, a wave which had gone into occlusion is shown as a LOW with center over Medicine Hat, Alberta. The occluded front accompanying this LOW is well marked by a discontinuity in wind direction and pressure characteristic.

The west-east section (fig. 2) for this morning shows in an exceptionally well marked manner the contrasts in temperature and moisture between the surface P_C air mass and the tropical air masses above. At Omaha, a surface temperature of $-2°$ and a q (specific humidity) of 2.6 grams is accompanied by a light SSE. wind. The temperature remains the same up to 1,200 meters while q drops to 1.8 grams. Then at 1,600 meters a 3° inversion is accompanied by a shift in wind direction to light WSW. and a q of 1.5 grams. This elevation is taken as the height of a surface of subsidence present in the P_C mass, which is also found at Cleveland and Boston on the same section. Above this inversion, an isothermal layer of 150-meter depth precedes an increase in temperature and q from 1° and 1.8 grams, respectively, at 1,900 meters to 7° and 4.4 grams, respectively, at 2,500 meters, accompanied by a shift of wind to NW., force 8. Then q drops to 3.2 grams but recovers slightly to 4.3 grams, and remains moderately high above to the top of the sounding. The intermediate dry layer may be a remnant of T_S (tropical superior) air,[3] which is so often found over the Southern States at intermediate and high levels, and which on these particular sections is present aloft over Cleveland and at intermediate levels over Dallas. However, the air above the P_C wedge seems to be mostly N_{TP}, as shown by the high temperature and moderate moisture content, and is being transported by strong NNW. winds. The presence of tropical air aloft accompanied by northwesterly winds is by no means unusual. Bjerknes[4] has shown that a tropical current flowing over a polar wedge acquires considerable curvature of its horizontal stream lines, due to the deflecting influence of the earth's rotation on a current of air which undergoes vertical divergence and convergence. In Bjerknes' example a tropical air mass lifted from the surface to 1,500 meters, during its ascent over a polar wedge, showed a turning of the stream lines from SW. at the surface to NW. and even to NNW. The author, in daily analyses of vertical sections during several months, has observed time and again tropical currents appearing aloft with NW. winds. Even over the eastern part of the country, the warm, moist T_G air is sometimes observed appearing over a P_C wedge as an NW. current.[5]

The Cleveland sounding for this morning is for the most part in P_C air. A layer of steep lapse-rate extends up to 2,000 meters, accompanied by a 10 St. Cu. cloud deck from 1,000 to 2,000 meters in which icing conditions are reported. Before the take-off, light rain and snow were observed, and evidently the P_C air, during its passage over Lake Erie, had acquired heat and moisture in its lower layers. Above the cloud deck a small isothermal layer is accompanied by a drop in q from 2.1 to 1.5 grams. This is taken as a continuation of the same surface of subsidence found at Omaha. Above this is a moderately stable layer of about 1,000 meters depth in which q drops to 0.6 grams. In the next 900 meters, the temperature increases 5° and q remains constant. At 4,000 to 4,600 meters occurs a 3° inversion and an increase in q to 1.0 grams. Above this inversion, at 5,200 meters q is 0.7 gram, which is higher than the value of 0.6 gram found 2 kilometers lower in the P_C air, but considerably lower than the value of 2.5 grams found at the same elevation in the N_{TP} over Omaha. This dry air is evidently the T_S air, a remnant of which was found at intermediate levels at Omaha.

At Boston the sounding remains entirely within the P_C current. A 400-meter thick St. Cu. deck is found at 1,000 meters, above an adiabatic layer; and above this the lapse rate is very stable. Between 1,800 and 2,400 meters, q drops from 3.0 grams to 1.9 grams, and this layer is taken as a continuation of the surface of subsidence found at Omaha and Cleveland. Above this the P_C air shows moderate stratification in temperature and moisture, which according to Willett is a characteristic of most deep P_C air masses.

On the north-south section (fig. 3), the sounding at Pembina shows the transition from P_C to N_{TP} air in the same well-marked manner as at Omaha. At 1,600 meters there is evidence of the same surface of subsidence, where a 3° inversion and a minimum of specific humidity occur. Above this level the temperature remains practically constant to 2,200 meters; between this elevation and 2,800 meters a 6° inversion and an increase in q from 3.5 to 4.3 grams are found, evidently corresponding to the transition from P_C air to N_{TP} air. However, the transitional zone between the two types of air really extends from 1,600 meters to 2,800 meters, since it is within this layer that q increases markedly. Above 2,800 meters we find temperatures and specific humidities characteristic of N_{TP} air. There seems to be no evidence of the intermediate layer of T_S air that is found at Omaha.

The sounding at Dallas on the same section shows a well-marked stratification, corresponding to three air masses. The first mass is a 1,700-meter surface layer of the older N_{PC} air which had moved slowly south several days before and had acquired considerable warmth and moisture, so much so that on the section this air mass is labelled "becoming T_G." Between 1,700 and 2,000 meters exists a transitional zone between the N_{PC} and T_S air, which is marked by a 2° inversion, a decrease in q from 7.9 to 4.0 grams, and a shift in wind from ENE., force 3, to NNE., force 2. At 2,500 meters a minimum of q is reached, 2.8 grams; above this level q increases to 3.7 grams at 3,600 meters, showing the existence of the overlying N_{TP} current, such as was found over Omaha. It is interesting to see that at Omaha the transitional zone between T_S and N_{TP} is bounded by potential temperatures of 308° and 310°, and at Dallas by 309° and 311°.

The surface map for the morning of October 26 (fig. 4) shows that the N_{TP} sector has gone into occlusion, the occluded front showing as a well-marked wind-shift line extending from Minnesota to southern Oklahoma. To the west of this front the 3-hour pressure characteristics are positive, and temperatures have dropped since the previous morning. For example, at Yellowstone Park and Cheyenne, Wyo., two high stations, which were in N_{TP} air on the morning of the 25th, the temperatures have decreased from 44° to 34°, and 48° to 38°, respectively, and the pressure characteristics have changed from negative to positive. The advance of the N_{PP} front eastward and southward was accompanied by thunderstorms at Dodge City, Kans., Sante Fe, and Roswell, N. Mex., although only light precipitation occurred.

[3] For a description of T_S air, see H. C. Willett, "The T_S Air Mass Designation as used at M. I. T,", Bulletin of American Meteorological Society, vol. 16, no. 5, May 1935.

[4] Bjerknes, "Explorations de quelques Perturbations Atmosphériques a l'aide de sondages rapprochés dans le temps." Geofysiske Publikasjoner, vol. IX, No. 9, 1932.

[5] For further discussion of this phenomenon, see H. R. Byers, "Change in an air mass during lifting" (not yet published).

The eastern limit of the N_{PP} air is found above the P_c wedge about 150 miles to the east of the surface wind-shift line. It is characterized by precipitation, and a discontinuity in pressure characteristic. While Davenport, Iowa, has rain and a steady 3-hour pressure fall of 0.10 inch, at St. Joseph, Mo., the rain, which amounted to 0.28 inch during the night, has ceased and the pressure is falling unsteadily, amount 0.02 inch, although the southerly wind shows that the station has not been passed by the occluded front (surface wind-shift line). At Kansas City it is still raining, with a southerly wind, and the pressure characteristic is an unsteady rise of 0.02 inch; at Columbia, Mo., it has not begun to rain, the wind is SE., and the pressure characteristic is a steady fall of 0.08 inch. Oklahoma City reports a thunderstorm during the night, although its wind is still SE. This upper air cold front and the surface cold front are joined in a smooth curve since of course they both mark the boundary of the N_{PP} air.

The P_c front in the northwest has moved southeastward, from Havre, Mont. on the 25th to Huron, S. Dak., on the 26th, and the occluded front is still present as a pressure trough from Sioux Lookout, Ont. to Qu'Appelle, Saskatchewan. The eastern P_c mass has now moved eastward to Bermuda and southward to the Gulf, bringing with it colder, drier air. For example, the temperature and dewpoint at Macon, Ga., dropped from 56° and 47°, respectively, on the morning of the 25th to 46° and 31°, respectively, on the morning of the 26th. The air mass, however, has not reached Brownsville, Tex., where temperature and dewpoint for both mornings are 72° and 67°, respectively, values which are characteristic for maritime tropical air in that region during the fall.

The west-east section for the morning of October 26 (fig. 5) maintains the same pattern as on the previous day, except that the P_c wedge has become much more shallow and the N_{PP} air has entirely displaced the N_{TP} air over Omaha. The P_c air over this station extends only up to 1,700 meters and is so much modified that it is called N_{PC}; at 1,700 meters the temperature and specific humidity are higher than at the surface, although the wind at this elevation is NW., force 4, while at the surface it is light southerly. The temperatures and moisture contents have risen markedly since the previous morning from the surface to 2,000 meters, while above 3,000 meters the temperatures have fallen considerably, although the moisture contents are about the same. The increased warmth and moisture in the N_{PC} air are due primarily to mixing with the warmer, moister Pacific air masses aloft and to falling precipitation, and only secondarily to its southern trajectory as shown by comparing the Omaha and Dallas soundings (fig. 6). While the latter sounding shows a steady decrease of q with elevation in the N_{PC} air, which would correspond to an upward transport of moisture from the ground, the latter sounding shows an increase of q with height, indicating that here the transport of moisture is downward from the moist Pacific air masses aloft. The marked cooling aloft since the previous day is due to the colder N_{PP} having displaced the N_{PP} air which was present above 2,500 meters on the previous day. Hence the N_{PP} is acting as a warm front relative to colder N_{PC} air and as a cold front relative to the warmer N_{TP} air. The fact that the moisture contents are high in the N_{PP} air probably shows that aloft Omaha is still on the frontal zone between the N_{PP} and N_{TP} air, as is already indicated on the surface map where the easternmost portion of the N_{PP} is found only about 150 miles east of Omaha.

The Cleveland sounding for the same section shows P_c air present up to 2,700 meters. On account of the eastward movement of the center of the HIGH from Lake Superior on the 25th to Chesapeake Bay on the 26th, the winds in the P_c air at Cleveland turned from northerly to southerly. This shift was accompanied by a considerable decrease in moisture content and temperature at lower levels within the P_c air, thus showing how the P_c air during its passage over Lake Erie on the 25th had acquired considerable heat and moisture in its lower levels, and how the return P_c air on the 26th had evidently never passed over the Lakes.

From 1,300 to 1,900 meters the temperature increases 5° while q reaches its minimum value of 1.2 grams. This evidently corresponds to the same surface of subsidence observed on the previous day. Above this level the temperature increases 2°, and q increases from 1.2 to 2.8 grams. Then a slight decrease in q is followed by a sharp increase from 2.7 to 3.3 grams in 600 meters. This intermediate dry layer, from 2,700 to 3,100 meters, is taken as the remnant of the T_s layer which was present in the section the day before; the upper layer is evidently the N_{TP} air which was present at Omaha on the preceding day. At Boston the sounding shows a similar stratification. From 800 to 1,400 meters, an inversion of 5° occurs, probably a turbulence inversion due to the strong NW. winds. Above this level exists a very stable layer, in which temperature decreases only 3° in 1,600 meters, and q from 2.0 to 1.6 grams. The surface of subsidence is taken within this layer, at a wind shift from NNW., force 8, to NW., force 8. From 3,000 to 3,400 meters the temperature increases 3°, and q increases from 1.6 to 2.2 grams. Then q decreases to 1.8 grams, and recovers slightly to 1.9 at 4,400 meters, where a small inversion of 0.5° occurs. The intermediate layer from 3,400 to 4,200 meters is taken as the T_s layer, and the layer above as the N_{TP} air, although the high moisture contents found in the N_{TP} air above Cleveland are absent, probably owing to the fact that at high levels the Boston sounding is in a transitional zone between the N_{TP} coming in from the west and the T_s which it is displacing. However, the top levels of the two soundings are very similar, Cleveland having a temperature and q of −12° and 1.9 grams, respectively, at 5,400 meters, and Boston, −13° and 1.3 grams, respectively, at 5,500 meters. It is interesting again to see that the transitional layer between the T_s and N_{TP} air is bounded at Cleveland by potential temperatures of 308° and 310°, and at Boston by 306.5° and 310°. This is in close agreement with the bounding values of the same transitional zone observed at Omaha and Dallas on the previous day.

The north-south section for the 26th shows considerable change since the previous day. A late ascent at Pembina gives us the first sounding through the P_c air which moved in from the northwest, and shows it to be a deep, cold, dry current. The temperatures and moisture contents have dropped at every level since the previous morning, the maximum temperature fall being 24° at 3,000 meters. This P_c current is relatively free from stratification, the only marked example of which occurs at 3,500 meters, where a 3° inversion and a sharp drop of relative humidity exist above an 8 A. Cu. cloud deck. This P_c air has not reached Omaha on the morning of the 26th, as is clearly shown by both surface and upper air data. The lower levels of the P_c air mass over Pembina are characterized by a steep lapse rate, and snow-squalls were reported at the surface at 7 p. m.

The Dallas sounding shows even more stratification than on the previous morning, due to the additional presence of a shallow P_C wedge at the surface which extends to about 800 meters, and which had moved in since the preceding morning. In this layer the temperatures have dropped slightly since the day before but the moisture contents have decreased considerably. Although the winds in this layer are from the SE. and SSE., there can be no doubt about the land trajectory of this air. Between 700 and 830 meters there is an increase in temperature from 11° to 16° and in q from 3.9 to 7.9 grams. Then at 1,100 meters, maxima of temperature and q are reached, 17° and 10.2 grams, respectively. This transitional zone of about 400 meters is accompanied by a shift in wind from SSE., force 7, to SW., force 5. Above 1,100 meters the temperature and moisture contents remain high to about 3,000 meters, and the winds are mostly WSW. This layer evidently is the greatly modified N_{PC} air which has almost tropical maritime properties. Between 3,000 and 3,500 meters, there exists a very stable layer in which the temperature decreases only 2°, and q decreases from 7.0 to 3.9 grams, accompanying a shift in wind to WNW. and probably to a still more northerly direction above. Then a fairly steep lapse-rate is found up to 4,500 meters where a minimum of q is found, 1.3 grams. Above this elevation q increases to 2.2 grams, decreases to 1.6 grams, and finally increases to 2.2 grams at 5,500 meters. The dry layer is evidently the T_S layer which was found at Dallas on the previous day, although the moisture contents are now lower. The increase in q at the top of this layer marks a rather broad transitional zone between the T_S and N_{TP} air, so that the stratification pattern above 800 meters is the same as on the previous day.

Looking back now over the surface and upper air maps for the 25th and 26th, certain clearcut features stand out, some of which are not in accord with Christensen's statements. First of all, there can be no doubt as to the fact that above the P_C wedge on the 25th along the Omaha-Cleveland-Boston section there exist only tropical air masses, the moist N_{TP} and the dry T_S. The N_{PP} air, which had not yet begun to ascend the P_C wedge, is present over the plateau, and its temperatures at the morning and evening observations are considerably higher than those of the P_C air, although clear skies prevailed over most of the region covered by the P_C air. Even on the morning of the 26th, when the N_{PP} air had begun to ascend the P_C wedge, nowhere in the N_{PP} air do we find as low temperatures as observed in the return P_C air. For example, on this morning, Yellowstone Park reports one of the lowest temperatures found in the N_{PP} air, 34° with a partly cloudy sky; yet Fort Wayne, Ind., in the return P_C air, has a temperature of 32°, also with a partly cloudy sky. This contrast is even more marked on the previous evening, where for example, Yellowstone Park, in the N_{PP} air at 8 p. m., has a temperature of 50° with a clear sky, while Des Moines in the return P_C air, has a temperature of 42° also with clear skies. Hence, it is seen that the lower temperatures found in the P_C air are not caused by clouds and precipitation as Christensen suggests, but result from actual temperature differences characteristic of the two air masses. This is also borne out by the isotherms in the west-east section for the 26th. For example the zero isotherm is found at about 3,400 meters in the N_{PP} air over Omaha and at about 1,600 meters over Cleveland which is in the return P_C air, and at about 1,300 meters over Boston which is still within the fresh P_C air.

In addition to the N_{PP} air being much warmer than the P_C air, it is also clearly seen that it is much more moist. For example, on the west-east section for the 26th, at 2,000 meters, we see that the N_{PP} air over Omaha has a q of about 4.1 grams, the return P_C air over Cleveland about 1.4 grams, and the fresh P_C air over Boston about 1.8 grams. Even in the return flow of P_C air over Omaha on the 25th, the moisture contents are very low, a minimum of 1.5 grams at 1,600 meters. Hence, there can be no doubt that the N_{PP} air is much more moist than the P_C air, instead of the reverse as Christensen states in trying to explain the clearing up in advance of the surface wind-shift line. As mentioned above, the high moisture contents observed in the return P_C air on the 26th at Omaha are not characteristic of return P_C air which in general acquires most of its moisture from the surface during the course of its trajectory to the south; hence the high moisture content must be explained mostly by falling precipitation from above. This brings up the question of the origin of the precipitation a hundred miles or so east of the wind-shift line, and the explanation of the clearing which occurred some 50 miles in advance of the surface wind-shift line.

From the maps for the 25th and 26th we see that it was not until the N_{PP} air began to ascend the P_C wedge that precipitation occurred. On the 25th, when the N_{TP} and T_S air masses were overrunning the P_C wedge, clear skies mostly prevailed east of the wind shift line at both the morning and evening observations. At 8 p. m. the N_{PP} mass had begun to overrun the P_C wedge only north of Huron. By 8 a. m. the next day, after the N_{PP} air had ascended the P_C wedge along most of the front, precipitation had broken out and was evidently of the shower type, 0.28 inch occurring during the night at St. Joseph and only 0.01 inch at Kansas City.

The lack of precipitation in the Midwest on the 25th despite the overrunning of the underlying P_C air by the fairly moist N_{TP}, was due to the combined effects of several factors; namely, the presence of the intermediate dry layer of T_S air which probably mixed with the moist N_{TP} air and thus caused lower relative humidities to prevail within the latter; the fact that the N_{TP} air was lifted only slightly in overriding the P_C wedge, whose average height between Omaha and Cleveland was only slightly greater than that of the average height of the plateau from which the N_{TP} air was coming; and lastly, the winds within the N_{TP} current were mostly from the NW. at Omaha and from the N. at Dallas which would ordinarily tend to cause the N_{TP} air to subside, since P_C wedges usually decrease in height southward. Actually, if we look at the north-south section for the 25th, the N_{TP} air, because of the presence of the T_S layer below it, seems to move southward with very little vertical displacement.

The precipitation which broke out over the Midwest on the night of the 25th–26th is, as we have seen, associated with the overrunning N_{PP} air. This does not mean that the precipitation is falling out of the N_{PP} air, because as in the case of the N_{TP} air only a slight amount of vertical displacement upward would result as the air moved over the P_C wedge, which was becoming more and more shallow. Furthermore the precipitation is evidently of the shower type and so would not ordinarily result from a pure warm front action. Hence, the remaining alternative is that the showery precipitation is due to cold front action between the cold N_{PP} air and the warm N_{TP} air above the stagnant P_C wedge. Looking for a precedent in cold front action between the N_{PP} air and the N_{TP} air on the surface, we see that between 8 a. m. on the 25th and 8

a. m. on the 26th, Santa Fe, Dodge City, and Roswell report thunderstorms as the N_{PP} air displaced the N_{TP} air at the surface, although very little precipitation occurred. The increase in cold front activity as both Pacific air masses overrode the P_C wedge is probably due to the increased instability of the two masses that resulted from the slight lifting they had undergone in ascending the P_C wedge from west to east. Hence, the clearing up which occurred in advance of the surface windshift was probably the usual clearing up that occurs after a cold front passage at the surface—the only difference being that this particular cold front passage occurred at some 2,000 meters above the ground.

Continuing with the analysis of the situation, we see from the surface map on the 27th (fig. 7) that the N_{PP} front over the southwest has advanced southeastward so that it has passed into the Gulf. It was accompanied by widespread thunderstorm activity on the night of the 26th–27th in Texas and Arkansas with the precipitation amounts ranging from light to moderate. The drops in temperature and dew-point since the previous morning at Corpus Christi and Brownsville, Tex., show quite distinctly that the N_{PP} air has displaced the warm, moist N_{PC} air, which is now called T_G. The fresh P_C air from the northwest has moved southward past Cairo, Ill., and eastward past Grand Rapids, Mich., while the eastern P_C air mass has moved eastward and southward and has been split by a tropical disturbance whose center, 29.32 inches, is located about 300 miles SSE. of Cape Hatteras. This air mass is now called N_{PC}, and at Hatteras it is evidently so much modified that it is called T_A.

The position of the upper air N_{PP} front on the evening of the 26th had been characterized by a wind shift from S. and SE. to SW. and also by a discontinuity in pressure characteristic. Showers accompanied the passage of this front, and thunderstorms occurred at Springfield, Mo., and Little Rock, Ark., during the day. The pressure tendencies in Illinois, Missouri, Northwestern Arkansas, west of the front, were for the most part positive while the tendencies to the east were negative. In western Michigan and southern Wisconsin, west of this front, the pressure tendencies were negative but were in general smaller than the negative tendencies to the east and northeast of the front, where precipitation was falling. On the morning of the 27th, the upper-air front is characterized principally by a wind-shift line from SE. to S., and is already beginning to exhibit signs of a temperature discontinuity. For example Saugeen, which is west of the front, reports rain with a SW. wind and temperature of 44°, while Parry Sound, to the east of the front has rain with a SE. wind and a temperature of 38°. The front becomes indistinct at the ground to the south, although the airplane soundings at Cleveland and Boston show that it exists between these two stations.

The west-east section (fig. 8) for this morning shows that at Omaha the fresh P_C air has displaced the older N_{PC} air at the surface. The temperatures and moisture contents have dropped since the previous morning and the winds are north-northeasterly at the surface and go around to NW. at 1,200 meters and to WNW. at 1,800 meters. This wind shift is accompanied by an increase in temperature from 1° to 4°, and in q from 2.7 to 4.8 grams. Above 1,700 meters the air is still N_{PP} and the flight was terminated at 3,100 meters because of icing conditions in a 10 St. Cu. cloud deck, whose base is at 2,800 meters. The cooling in the N_{PP} current and the condensation in it above 2,800 meters are evidently due to forced ascent over the P_C air coming in at Omaha as a steep wedge, as is seen more clearly on the north-south section for the 27th (fig. 9).

The Cleveland sounding shows the N_{PC} air extending up to 2,000 meters, the temperature and specific humidities being considerably higher than on the previous day. From 1,300 to 2,000 meters, q increases from 3.2 to 6.4 grams, and remains quite high until about 3,500 meters, after which it decreases quite rapidly so that at 5,400 meters q is 0.8 gram. The air above 2,000 meters is evidently the N_{PP} air, although compared to the N_{PP} air at Omaha on the 26th it is cooler level for level, and its moisture contents at lower levels are higher, and at higher levels are much lower. The lower temperatures throughout, and lower specific humidities aloft, are probably due to the Cleveland sounding being well within the N_{PP} current, so that the characteristic coolness and dryness of the N_{PP} air aloft are revealed. Unfortunately, there are no apparent signs at the surface between Cleveland and Boston to show how far eastward the N_{PP} air has advanced, so that it is difficult to determine just how far from the frontal zone the sounding is. The high moisture contents at the lower levels of the N_{PP} air mass are probably caused by the presence nearby of the T_G air that was present at Dallas on the previous morning. This T_G air has evidently moved swiftly up the occluded trough during the preceding 24 hours. The pilot balloon winds at Indianapolis, Ind., at 6 p. m. on the 26th show a SW. current which increases in velocity from 30 miles per hour at 1,200 meters to 52 miles per hour at 4,200 meters. That the upper levels of the N_{PP} air retain their characteristic dryness is probably explained by the fact that at Dallas on the 26th the T_G air was found only up to about 3,000 meters and probably is not much higher to the south of Cleveland. Unfortunately, the lack of an airplane station between Cleveland and Dallas prohibits a more rigorous analysis.

At Boston, the sounding penetrates a layer of N_{PC} air, extending up to 1,000 meters, which has recently passed over the ocean. The moisture contents are higher, and from 1,000 to 1,200 meters there is an inversion of 2.5° through which q decreases from 3.5 to 2.2 grams and the wind shifts from SSE. to S. to SSW. From 1,200 to 1,800 meters the temperature increases 2° and q increases from 2.2 to 2.9 grams. This is evidently a transitional zone between the N_{PC} air below and the tropical air above. Between 2,100 and 4,200 meters the temperature decreases only 7°, and q decreases from 2.9 to 2.2 grams—both very small decreases. This layer is evidently a mixture of the T_S and the N_{TP} air that were present on the previous day. At 5,500 meters the temperature and q are −13° and 1.6 grams, respectively, which is not very much different from −12° and 1.9 grams observed at 5,400 meters at Cleveland on the 26th in the N_{TP} air.

The north-south section at noon of the 27th (fig. 9) shows that at Pembina the P_C air is much warmer level for level than it was the previous evening and that it now possesses considerable stratification, probably on account of subsidence. Two distinct inversions are marked on the sounding, and several isothermal or near-isothermal layers are also found below these inversions.

The Dallas sounding shows that at the surface the N_{PP} air has displaced the N_{PC} air that was present on the previous day. The temperature at about 600 meters has risen from 11° to 18°, and q from 4.2 to 8.0 grams, showing again the increased warmth and moisture of the

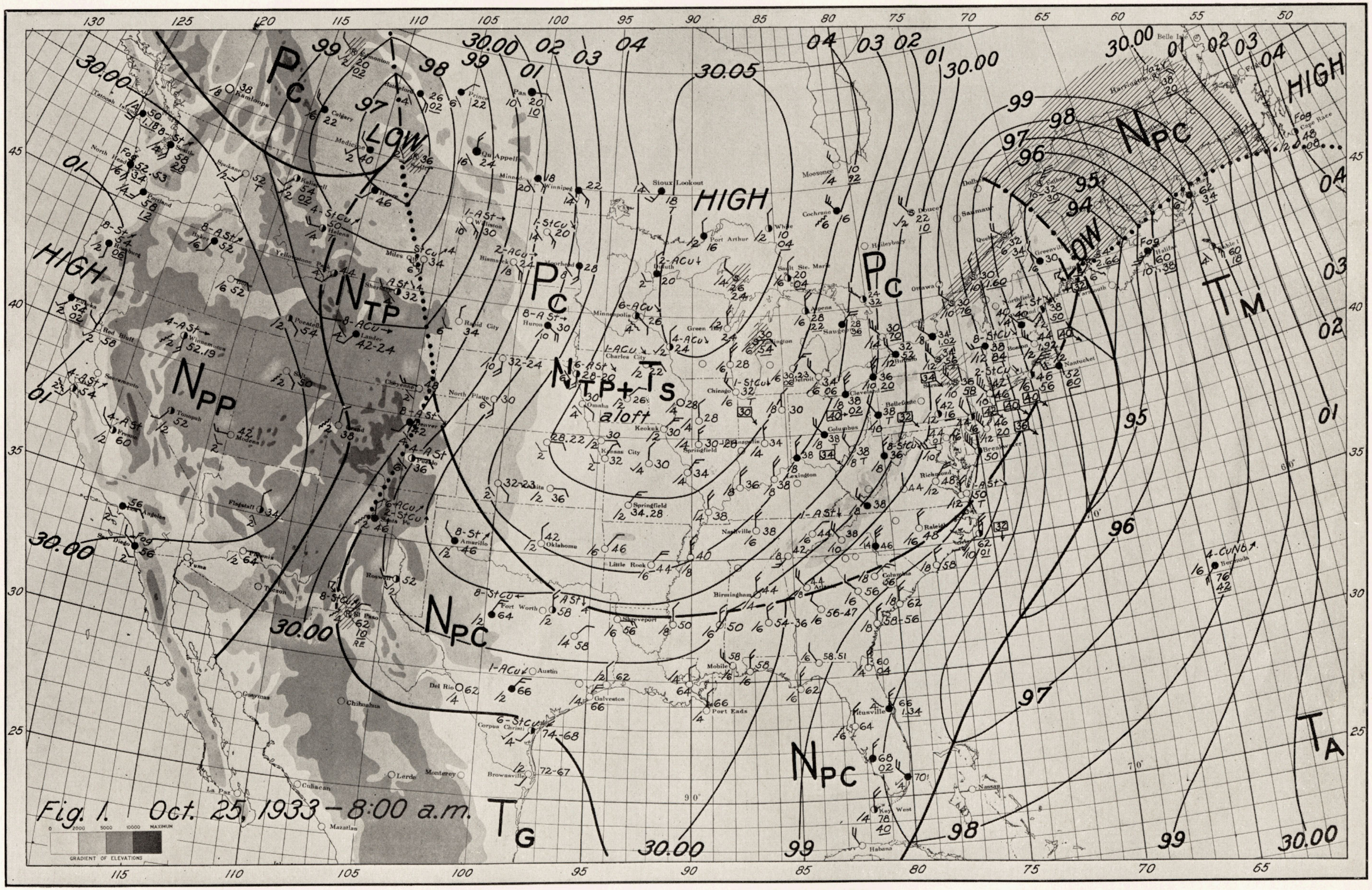


Fig. 1. Oct. 25, 1933 – 8:00 a.m.

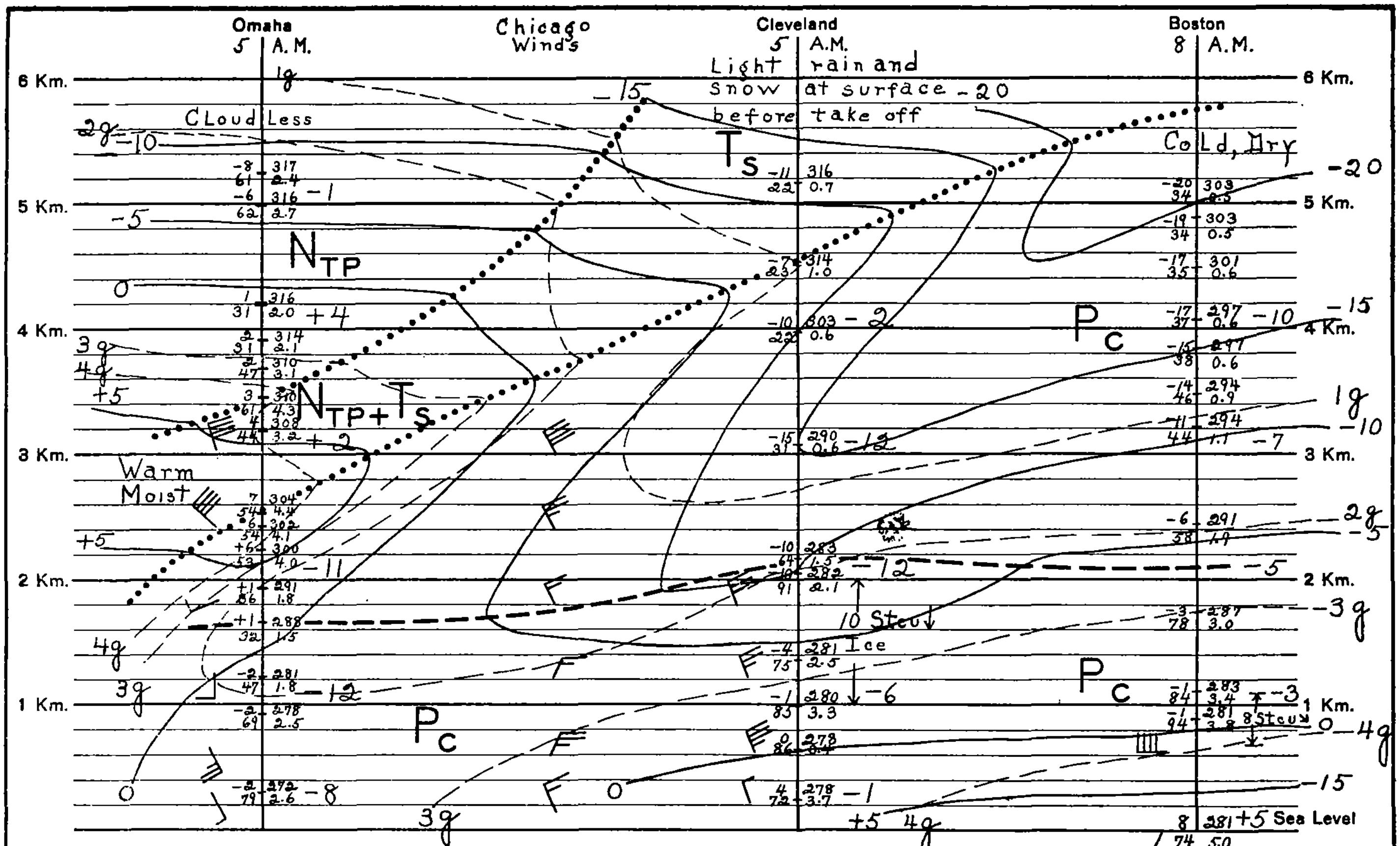


Fig 2. October 25, 1933

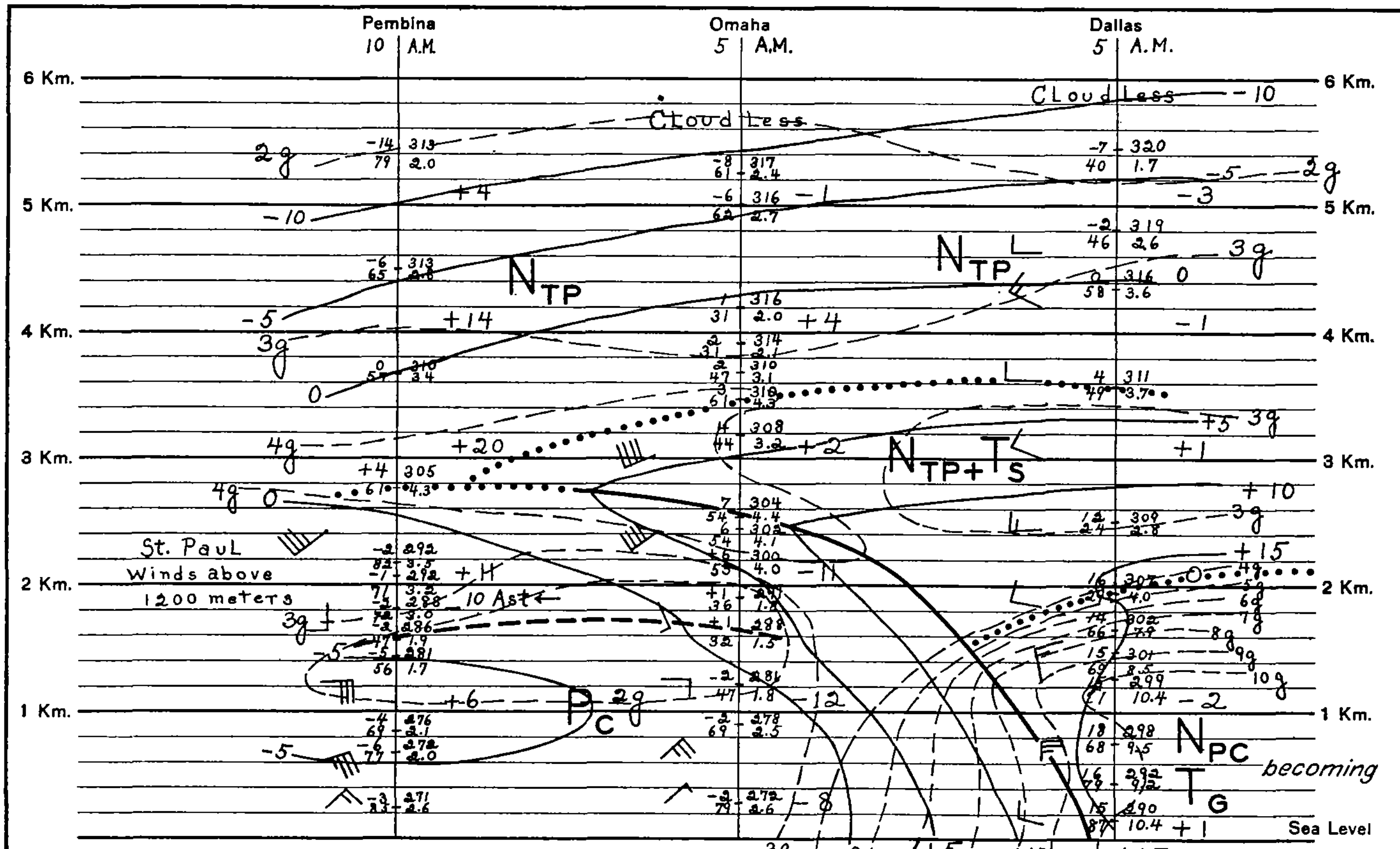


Fig. 3. October 25, 1933

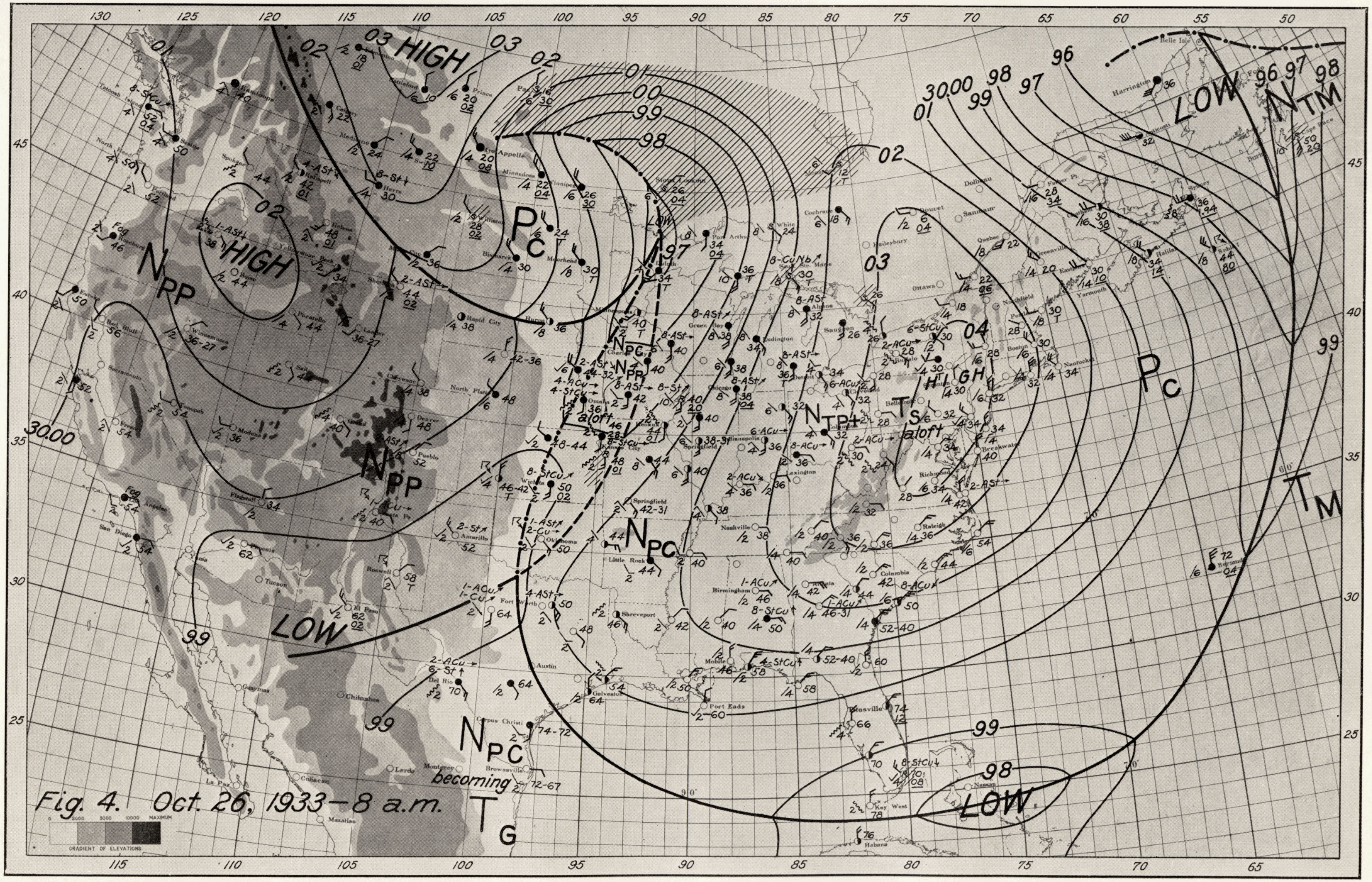


Fig. 4. Oct. 26, 1933—8 a.m.

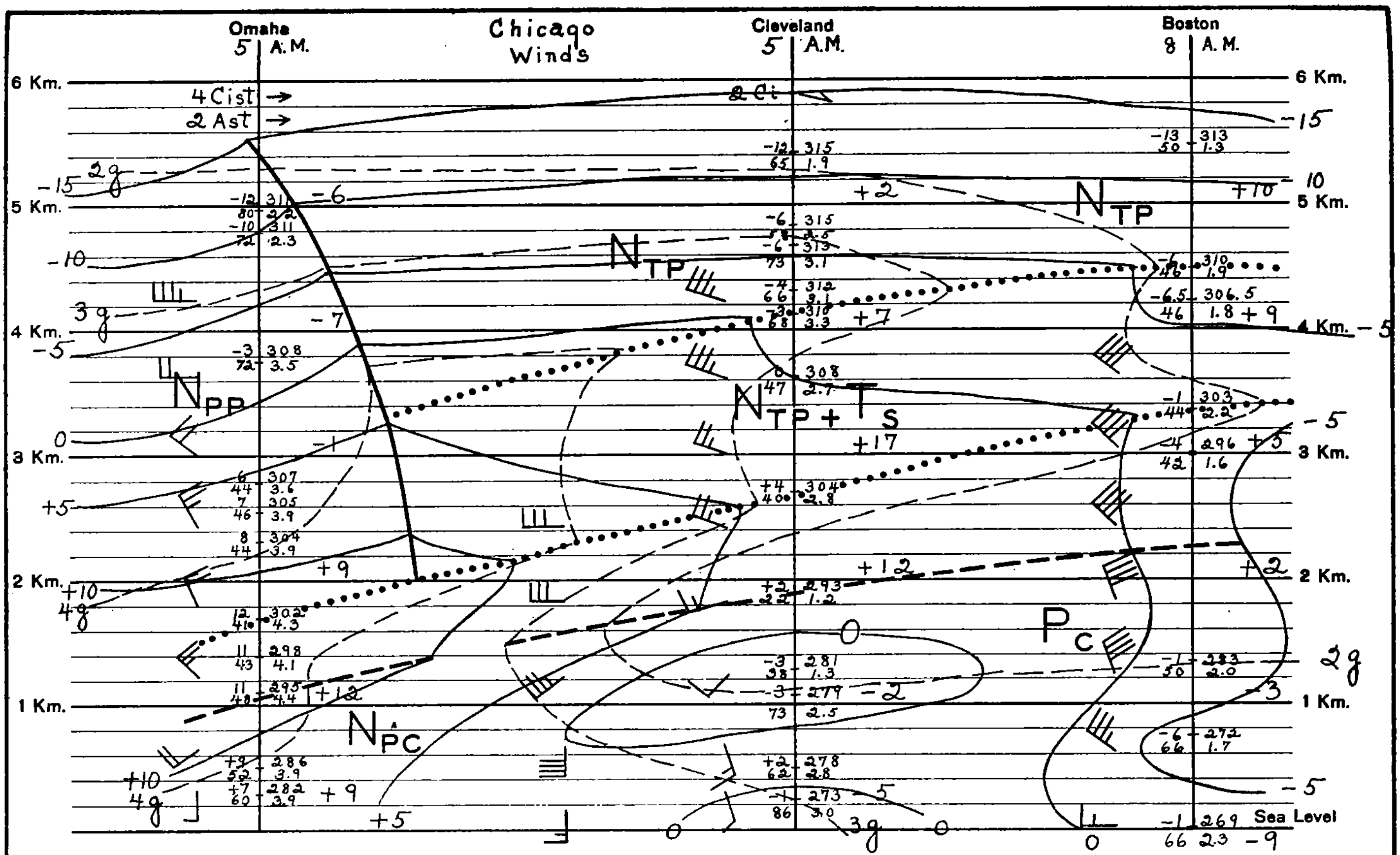


Fig. 5. October 26, 1933

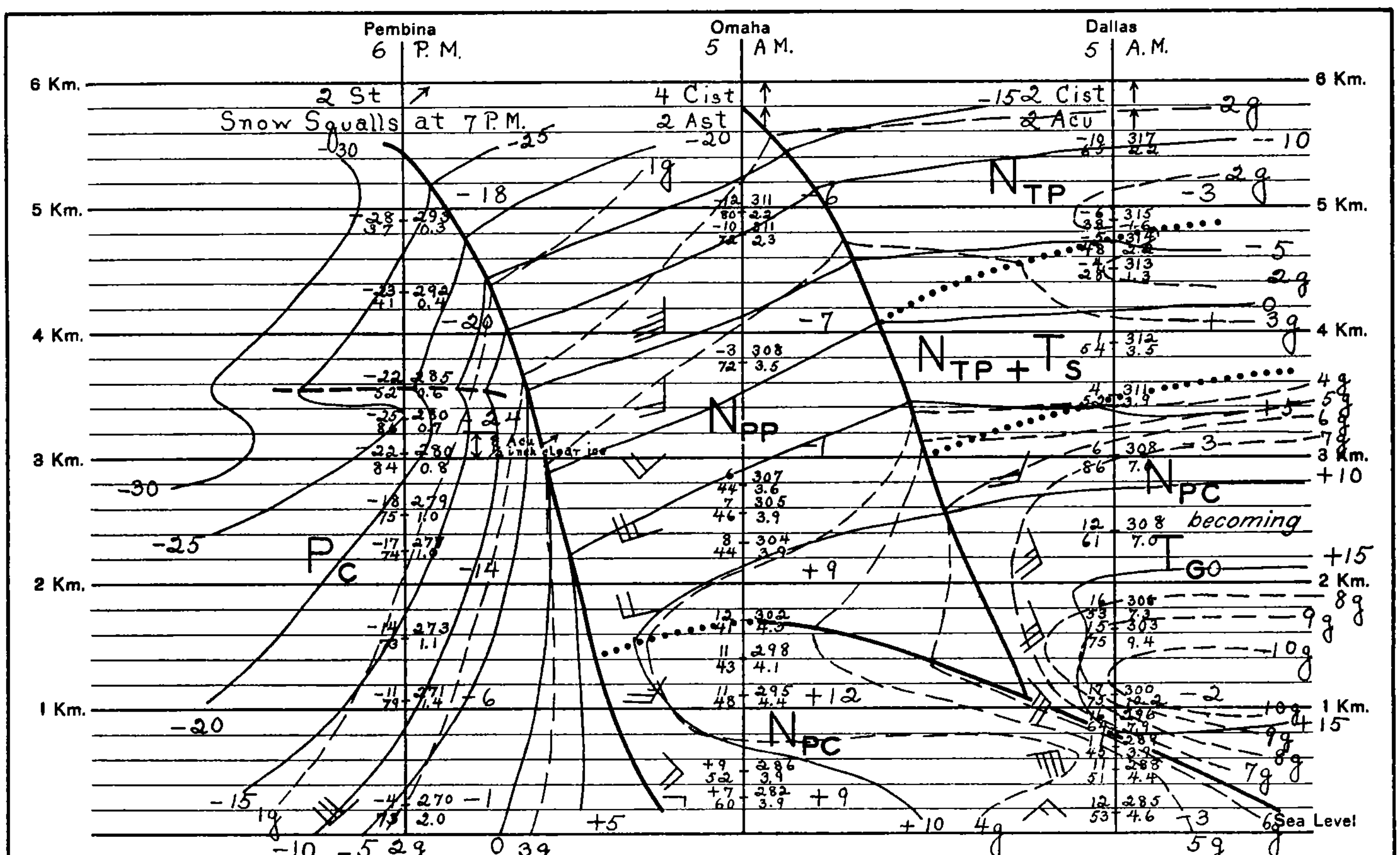


Fig. 6. October 26, 1933

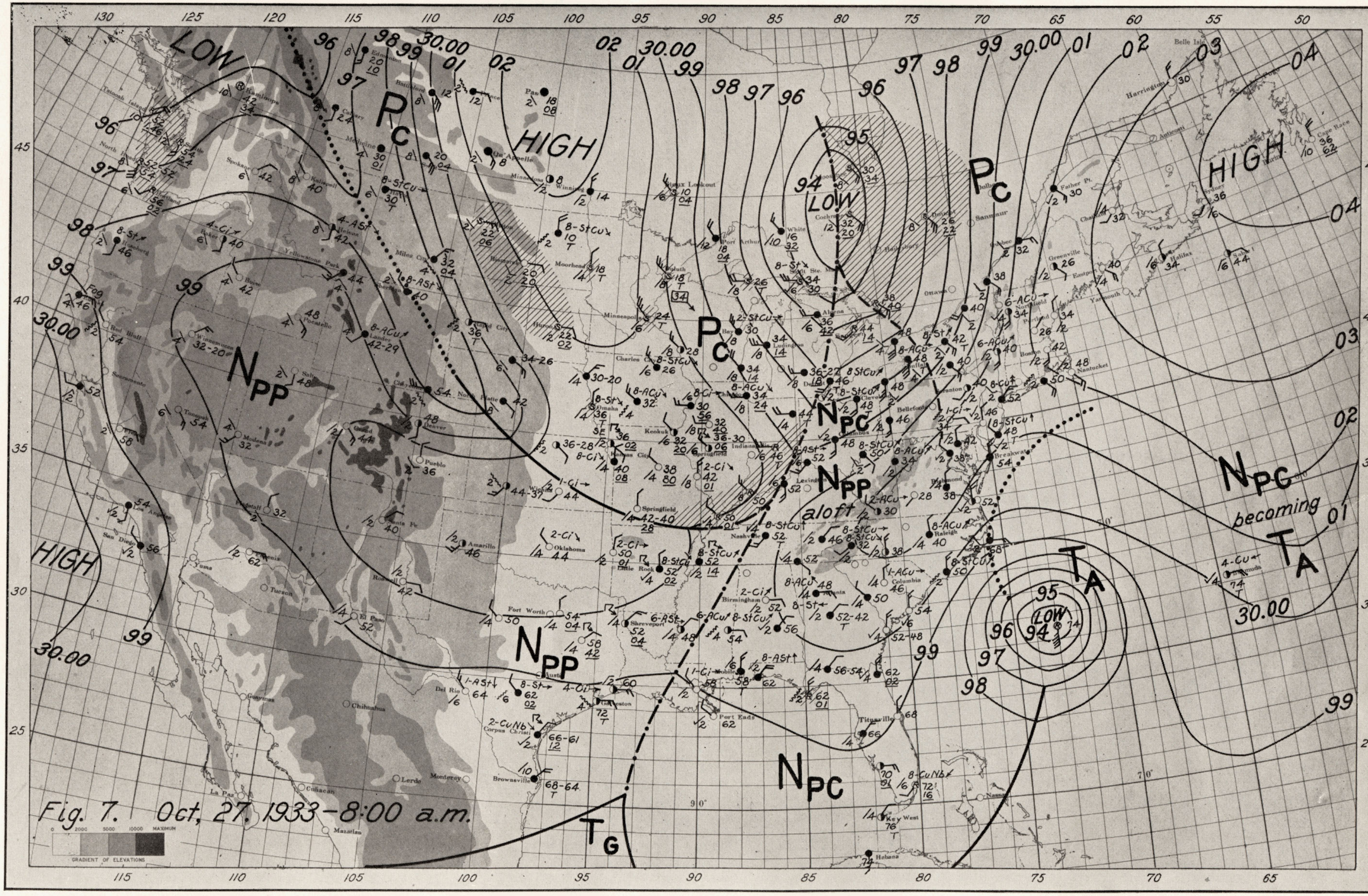


Fig. 7. Oct. 27, 1933—8:00 a.m.

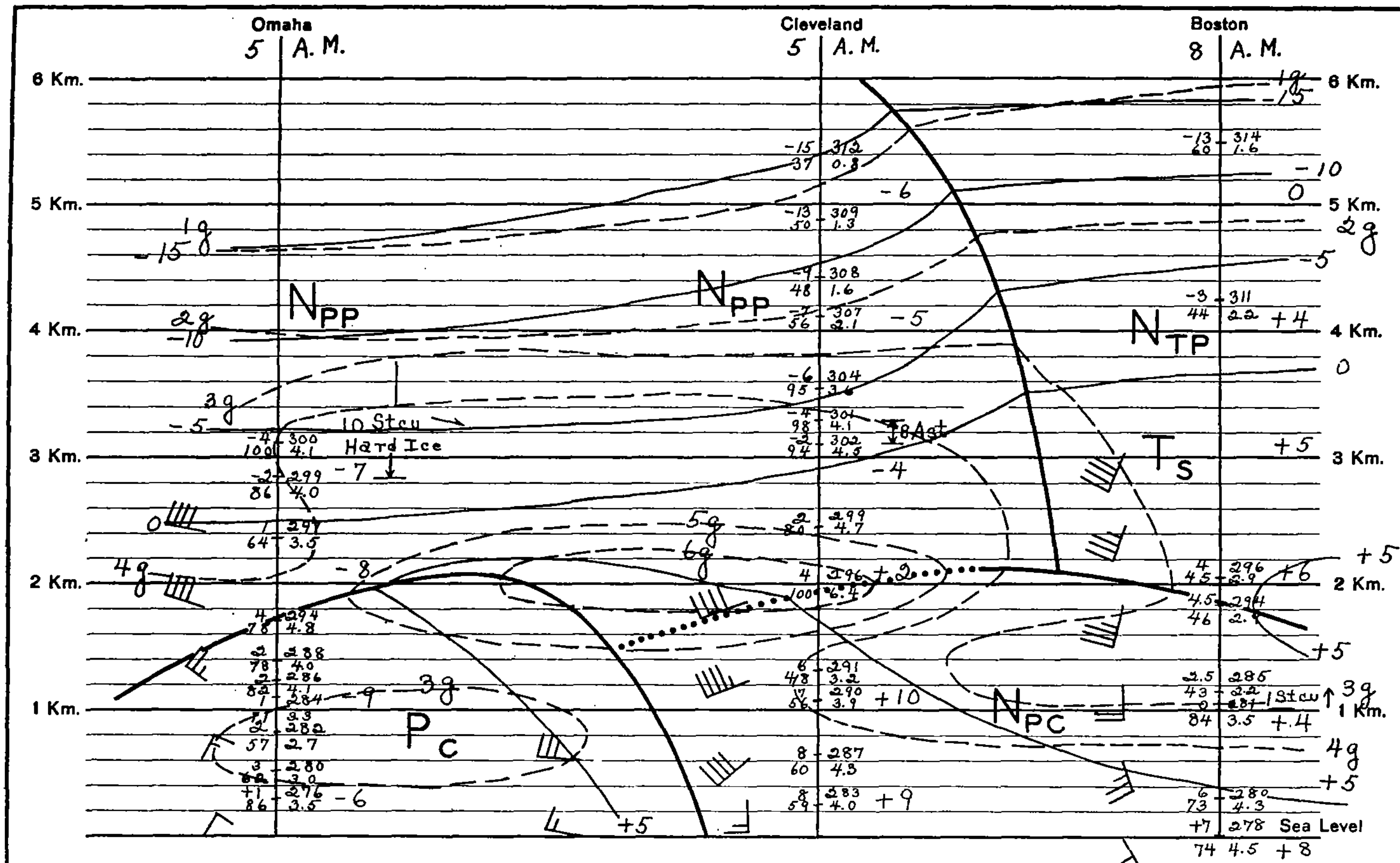


Fig. 8. October 27, 1933

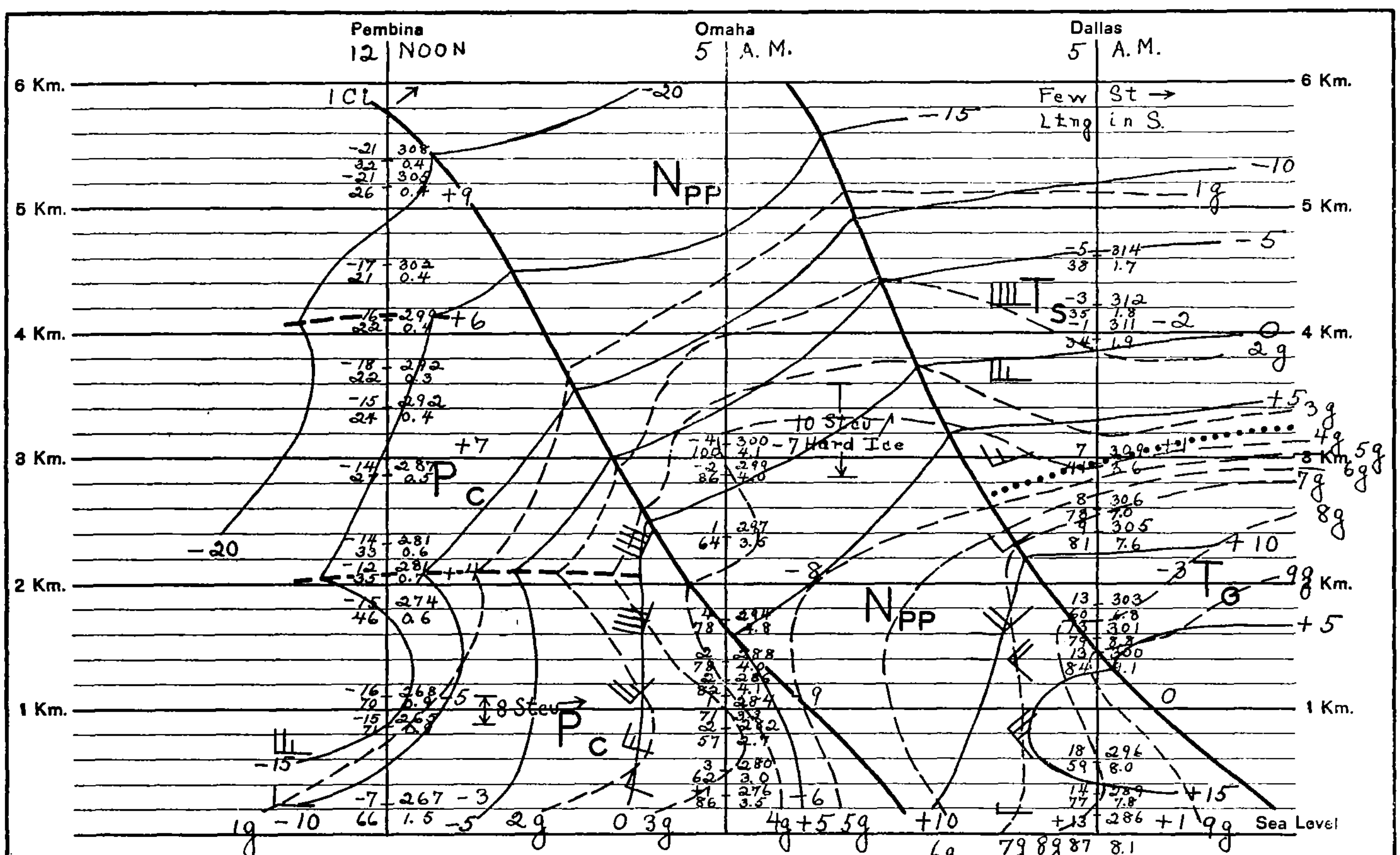


Fig. 9. October 27, 1933

N_{PP} air relative to the N_{PC} air. The winds are N. and NE. from the ground up to 1,200 meters. Between 600 meters and 1,400 meters there is evidently a transitional zone between the N_{PP} air and the T_G air. The wind shifts from NE. to NW. and q increases from 8.0 to 9.1 grams and remains quite high until about 2,600 meters. The layer from 2,400 to 3,000 meters shows a moisture decrease from 7.6 to 3.6 grams. Above 3,000 meters, the lapse rate is fairly steep and the moisture content low. This air is the T_S air that has been present above the N_{PC} (T_G) air at Dallas for the past 2 days. Whether or not the N_{TP} air exists above the T_S air as it did previously cannot be said, since the sounding does not extend to sufficient height.

ERRATA IN THE ILLUSTRATIONS

(For explanation of the symbols in the illustrations, see p. 213)

FIGURE 1.—At Bismarck, N.Dak., Huron, S.Dak., and Valentine, Nebr., the pressure tendencies should be steady *falls* instead of steady rises.

FIGURE 4.—At Sault Ste. Marie the pressure tendency should be a steady *fall* instead of a steady rise. The front over the Gulf of St. Lawrence should be a *warm* front instead of an occluded front.

PRELIMINARY MEASUREMENTS OF ULTRA-VIOLET AT BLUE HILL METEOROLOGICAL OBSERVATORY

By RICHARD F. BAKER[1]

[Blue Hill Meteorological Observatory of Harvard University, Milton, Mass., July 1935]

Preliminary measurements of solar ultra-violet radiation were initiated at the Blue Hill Meteorological Observatory in April 1934, with an instrument loaned by the Biological Laboratory of the Long Island Biological Association through the courtesy of Dr. Hugo Fricke.

The sensitive element consisted of a cadmium photoelectric cell, the construction of which merits a brief description. The cell was of the vacuum type, and was constructed of Corex D glass. In shape it was spherical, 2 inches in diameter; attached was a tubular neck 5 inches long, through which passed the anode lead. The anode itself was a nickel ring one-half inch in diameter supported in the center of the cell by the anode lead. The cadmium was deposited directly on the glass surface by a process of successive distillations through a series of small bulbs. To provide a window, the cadmium was then locally distilled off a circular area one-half inch in diameter on the side of the cell. Contact with the cadmium surface was made through a tungsten-Corex D seal in the end of the bulb opposite the neck.

The anode of the cell was connected directly to the fiber of a string electrometer through a metal tube to insure shielding from outside electrical disturbances.

In practice, the electrometer was charged by means of B batteries to 135 volts, the string being at a positive potential with respect to the cadmium surface. After focussing the cell on the source of radiation by means of a pin-hole focussing device, the photoelectric current generated by the radiation was allowed to discharge the electrometer.

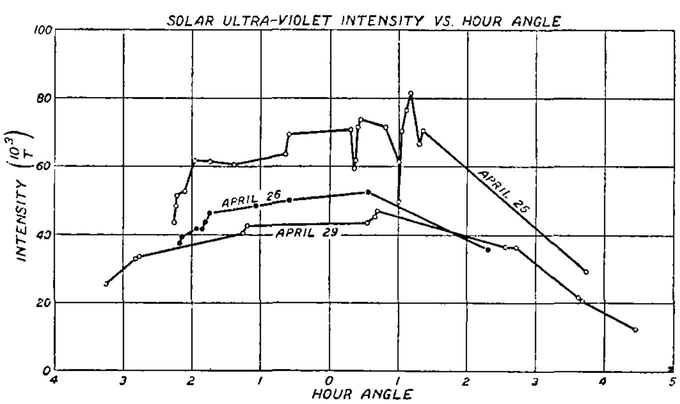
The number of electrons released from a photosensitive surface per unit time is directly proportional to the radiation intensity of given wave-length incident on the surface. Since the rate of discharge of the electrometer is directly proportional to the number of electrons coming to the string from the cell in unit time, it is obvious that the rate of discharge is directly proportional to the radiation intensity of those wave lengths to which the cell is sensitive.

The long wave threshold for cadmium is very close to 3,150 Å;[2] consequently the cell measured no radiation of wave length greater than 3,150 Å. The Corex D glass of the thickness used transmitted no radiation of wave length less than 2,800 Å. Accordingly, the cell was sensitive only to radiation in the spectral range 2,800–3,150 Å. The sensitivity curve of the cell in this range corresponded closely to the sensitivity curve of the human skin to erythema, since the instrument was designed originally for an investigation of the biological effects of solar radiation. The intensities as measured, then, are directly proportional to the erythemal effectiveness of the radiation.

An illuminated scale and telescope were built into the instrument to give a means of measuring the rate of discharge of the electrometer. The rate of discharge was taken as the reciprocal of the time required for a five division fall on the scale. $10^3/t$ was taken for convenience rather than $1/t$, in reducing the data.

The cell aperture consisted of a system of concentric circular brass rings which fitted snugly in a hole in the metal case which held the cell. The aperture used in this investigation was such that when focussed on the solar disk the cell intercepted radiation from a solid angle of 1.8 steradians, or 28.8 percent of the maximum possible area.

The natural leak of the instrument was zero at the time of the observations.



Curves I, II, and III are for three typical days, and represent ultra-violet intensity plotted as a function of hour angle. Table 1 contains the complete set of data, including pertinent comment on the state of the sky at the time of the observations. The marked variations of intensity over a short period, particularly on April 25, are rather remarkable. A cause of these variations cannot be certainly assigned at this time. It seems plausible, however, that absorption and scattering by cloud formations are responsible, at least in some degree.

From the standpoint of the science of meteorology, and also in view of the practical importance to public health of this region of the solar spectrum, it is obvious that the problem of short-time changes in solar ultra-violet intensity merits further investigation.

[1] Department of Physics, University of Rochester, Rochester, N. Y.
[2] Hughes and Du Bridge. Photoelectric Phenomena. New York, 1932.